March 10, 1964

To Chairman and Members
of R. N. Sub-Committee:

Enclosed is a revised version of our working group report finally reviewed by the group listed below at the Winter Meeting in New York.

If you have any further comments, please send them to Mr. Rorder directly with a copy to me. Thank you.

Very truly yours,

T. W. Liao, Chairman
Working Group No. 4
"Line & Station Components"

RECEIVED
MAR 17 1964
ENG. DEPT.

F. Reed Dallye
Aluminum Company of America
536 Alcoa Bldg.
Pittsburg 19, Pennsylvania

F. A. Denbrock
Commonwealth Associates
209 E. Washington Avenue
Jackson, Michigan

C. D. Fiero
Mechanical Engineer
Lapp Insulator Company
LeRoy, New York

O. Nigol (J. R. Leslie)
Research Division
Hydro-Electro Power
Commission of Ontario
620 University Avenue
Toronto 2, Ontario, Canada

T. W. Liao (Chairman)
Engineering Research
General Electric Company
6901 Elmwood Avenue
Philadelphia 42, Pennsylvania
SA.4-1500, Ext. 8221

C. J. Miller
Research Engineer
Ohio Brass Company
Barberton, Ohio

H. H. Newell
Worcester Polytechnic Institute
Worcester,
Massachusetts

P. D. Tuttle
Aluminum Company of America
Massena,
New York

F. W. Warburton
New England Power Service Company
939 Southbridge Street
Worcester 10, Massachusetts

SECTION ON "LINE AND STATION COMPONENTS"

FOR

RADIO NOISE SUBCOMMITTEE REPORT

CONTENTS

1. GENERAL DISCUSSION

2. RIV VERSUS RI

3. PROPOSED RIV LIMITS

4. CONDUCTOR ACCESSORIES AND LINE HARDWARE

5. FLOATING GAPS AND UHF NOISE

6. MYSTICS OF TRANSMISSION LINE NOISE

7. BIBLIOGRAPH

8. FIGURES 1 AND 2

9. MEMBERSHIP OF WORKING GROUP ON "LINE AND STATION COMPONENTS"

1. GENERAL DISCUSSION

In addition to the radio noise from the line conductors, there are other components in the power transmission system that also produce radio noise under normal operating conditions. Such components as insulators, conductor accessories, lightning arresters, switchgear and transformers, etc., are referred to herein as line and station components. The radio noise generated from these components may be different from the conductor noise, both in noise level and in frequency band.

For instance, insulators and accessories of EHV lines are placed at intervals several hundred feet apart and their noise generation is, therefore, scattered as contrasted to the numerous corona sources that might occur along the surface of the conductors. Consequently, the contribution of the former is expected to be smaller, unless the conductor noise is kept unusually low by a special design, such as over-sized conductors. This condition is often true for lower voltage lines, especially of 69 KV and below. When sparking is found in insulators or from hardware, much higher frequency components than the conductor noise will be expected.

Station components are all located within a station, which may be many miles from another station. Therefore, the centers of their noise generation are scattered at even greater distances. Furthermore, since the noise generation is localized in individual stations, their effect on the RI level at a distance from the station will be smaller, because the noise attenuates along the line. In addition, the station components,

in general, have high capacitance to ground which offer low impedance to radio frequency noise. Therefore, it is even conceivable that when a low noise component is put in a station, it could lower the over-all noise level of the station, because the noise reduction due to its low impedance may be greater than the noise contributed by the component.

Where several lines are terminated at a sub-station, radio noise from one line may be coupled to another line by induction or through power transformers. Experiences show that the inductive coupling between adjacent lines may be considerable. Special considerations must be given to the case when one of them is a low voltage line, which may carry the noise to residential area. Radio noise voltages that are transmitted from one side of a sub-station to the other side through transformers and other station equipment are found to be relatively small because of the low impedance of the sub-station, particularly for large sub-stations.

2. RI VERSUS RIV

The nominal radio influence (RI) level of a transmission line is determined in fair weather with a radio noise meter having a vertical antenna at some designated distance laterally from the outer line conductor. It is expressed in terms of microvolt per meter. For instance, the RI level of a 230 kv line might be 50 μv/m (Using a quasi-peak meter with 6 KC bandwidth at 1 Mc) at 100 feet from the line. On the other band, the radio influence voltage (RIV) of an insulator string or a station equipment is to be measured according

to a standard NEMA-107 method[1], in which the meter is coupled capacitatively to the apparatus under test and is expressed in terms of microvolts. For instance, the RIV of a 230 KV disconnect switch might be 1000 to 2000 μv.

In the NEMA circuit the noise is measured at 1 Mc conductively with a noise meter with little, or no, attenuation between the equipment and the meter. But when the component is placed on a transmission line, its noise propagates along the line, producing electromagnetic waves around the line conductors. If a radio noise meter is placed in the vicinity of the line, a voltage will be induced at its antenna. The magnitude of the induced voltage is inversely proportional to approximately the square of the distances between the meter and the line up to $1/2\ \pi f$, where f is the tuned frequency of the meter. Thus, if a noisy component is far away from the location of the meter, the noise suffers two types of attenuation; first, it attenuates longitudinally along the line and, then, laterally from the line to the meter. Both types of attenuation have been determined analytically[2] and experimentally[3].

The rate of noise attenuation differs for different line configurations. The longitudinal attenuation of the principle mode of propagation is as much as 6 db per mile and laterally an RIV to RI ratio[4] is between 200 to 300 at 100 feet from the line. Thus, if a noisy insulator string having a RIV of 2000μv is located over a mile from the meter which is placed 100 ft. laterally from the transmission line, then the meter would register less than (2000/2 x 200) or 5 μv/m, as

illustrated by the top sketch of Figure 1. However, if the same insulator string is placed in a station with the same distance from the meter, the meter would read even less than 0.5 μv/m, as illustrated by the bottom sketch of Figure 1. The reason lies in the fact that a radio noise source produces a given noise current independent of the impedance of the circuit in which it is measured. Since the impedance of a station is, in general, less than a tenth of the NEMA-107 circuit, the same insulator string would produce less than 200 μv in the station.

It is recognized that a complete description of the RI versus RIV problem would entail the use of a model three-phase system. Not only does radio noise propagate by means of a line-to-ground component (as described above), but also by line-to-line modes without any current flowing through ground. Because of that, the line-to-line model attenuation rates are significantly lower than the line-to-ground rate, and thus the effects of the line-to-line modes are more pronounced as the distance becomes farther away from the source. At present, work on a complete model analysis for the "discrete source" situation (as described above) is in progress.* In general, one might expect that the noise level at 100 ft. from a three-phase line may be twice of the single phase case described above, although the estimate is very rough and is depending on many factors of the line in question.

* Mr. LaForest plans to submit an IEEE paper on this subject. If he has a Paper No. before submission of our paper, a reference may be made of his paper.

3. PROPOSED RIV LIMITS

The NEMA-107 method of measuring radio noise voltages was documented in 1940. However, the measuring techniques and instruments have improved over the years. Consequently, a revision of the existing NEMA-107 Method and the new ASA Specification C63.2 for Radio Noise and Field Strength Meters are being discussed and will be officially issued soon.* However, the RIV limits for the line and station components of the various voltage classes have not been seriously reviewed and no proposals of such limits for the EHV components have been suggested.

It is the opinion of the working group (see membership list) that the existing NEMA RIV Limits are conservative and that the limits for EHV station equipments may be raised proportionally according to the system voltages because of the fact that the distances between substations are farther apart.

Another reason which is not so obvious, is that station equipment of EHV classes are in general larger in physical dimensions and consequently have higher capacitances to ground. As mentioned previously, higher capacitance of the station equipment means lower impedance for the substation, resulting in an overall lower RI level for the transmission system. However, considerations should be given to suppressing station equipment RIV that can be cheaply achieved, because conductor noise may be suppressed in the future to a point that station noise becomes dominant.

* See Attachment No. 1

A proposed RIV Limits ** for insulators and hardware assemblies of the various voltage classes at a test voltage 110% of nominal line-to-ground voltage is shown in Figure 2. If the insulators are used in a station, the limits can be raised perhaps by a factor of several because of the low station impedance effect mentioned previously.

The RIV limit of other station equipment can also be raised above that shown in Figure 1 by a similar factor. In fact, the RIV values for some station equipments are kept low, not because of their radio influence but, because of the fact that high RIV often indicates internal corona which may lead to ultimate failure of the equipment. For instance, the RIV value of a power transformer is much lower than its NEMA RIV Limit when it is free of internal corona. On the other hand, RIV values of other types of station equipments, such as disconnect switches, are entirely due to external corona which does not affect the quality of the equipment. Extremely low RIV limit on such type of components would increase the cost of the equipments without upgrading their performance. Therefore, it is important that the NAME RIV Limits should be reviewed so that the cost and performance of the EHV equipments may be kept in balance.

** See Attachment No. 2

4. CONDUCTOR ACCESSORIES AND LINE HARDWARE

Along with insulators and insulator strings, the conductor accessories (such as joints, deadends, dampers, armor rods, spacers) and line hardware (such as suspension clamps, grading rings, yoke plates) are considered as possible radio noise sources on a transmission line. However, unlike the situation with insulators, there have been no existing or proposed RIV limits for the various voltage classes of conductor accessories and line hardware. Reliance has been placed on the manufacturers of these items to provide designs that give satisfactory corona and RIV performance on the lines to which they are applied. The criterion of "no visible corona" from accessories and hardware at the voltage at which the conductor itself develops corona has been adopted by many as satisfactory because when there is no visible corona there is no RIV and because there are no hidden regions where corona could not be seen, as there are in the case of insulators. The standard NEMA RIV circuit is used to read RIV over a voltage range from well below working voltage to such values that corona does occur and thw RIV meter indications provide a sure check on the presence of any corona that might escape visible notice. As with RIV limits, there are no standard test conditions and procedures for use in "visible corona" testing of accessories and hardware although the factors influencing the test results are, in general, well recognized and the results themselves have been satisfactory as evidenced by lines in service.

One factor is the surface voltage gradient. In the controlled but more confined environment of the indoor laboratory, this gradient is higher than it is for the same voltage on the operating line. The gradients of the conductor on the line and in the laboratory may be calculated and test voltages chosen to develop the same gradient as the working value. Or the gradient may be measured by means of simple devices to be the same in both instances. Again, because it is necessary to use the appropriate conductor as a part of the set-up when some accessories (eg. joints) are to be tested, it is convenient to use the conductor as a reference for all accessories and hardware associated with it. In effect, the conductor becomes a gradient reference that automatically corrects for the differences in configuration between the line and the laboratory. In brief, the corona voltage under working conditions and the corona voltage under test conditions indicate the same surface gradient.

Surface condition is another factor sometimes taken into account. Conductor, accessories and hardware are subject to weathering and contamination in service. Weathering refers to that hard, close-grained, adherent coating that develops on energized parts and which cannot be wiped or washed off. It cannot be simulated with confidence but invariably improves the RI performance of a working line. Contamination refers to temporary deposits of dust, pollen, insect parts, and other air-borne particles that are not fused into becoming part of the weathered coating but which can be wiped off or washed off. Such contamination is adverse in the production

of RI but varies so widely in type, amount, and influence, a simulation of the condition is difficult to agree upon. Therefore, the standard to be used as the reference for test is logically clean, new conductor.

In summary then, a suitable and adequate criterion for judging the RI characteristics of conductor accessories and line hardware may be expressed thus:

"Conductor accessories and line hardware shall be tested while fitted to the conductor with which they are to be used. The test items and conductor shall be in the new, clean, and dry condition. The visual corona voltage of the items under test shall be equal to or better than the visual corona voltage of the conductor to which they are attached."

5. FLOATING GAPS* AND ULTRA-HIGH FREQUENCY NOISE

One of the powerful tools in attenuation experiments is the so-called "Floating Gap" such as those developed by Prof. L. N. Stone and Prof. H. H. Newell. A floating gap is essentially a spark gap with a relatively large capacitance which can be hung on a line conductor. The radio noise produced by such a gap can over-ride any existing noise of an energized transmission line over a wide frequency range, thus attenuation and similar measurements can be made without interrupting power transmission.

Valuable data have been obtained by the use of such gaps, not only on rates of noise attenuation, mentioned previously, but also the determination of station impedances, noise coupling factors between circuits and the like. Photographs of two such gaps are shown in Figure 3. New gaps of improved characteristics are still being developed.

It is well known that the line conductor noise falls off rapidly beyond 10 megacycles. However, the noise produced by line or station components can have frequency components beyond hundreds of megacycles. For instance, sparking has been observed at string insulators with light mechanical loads on them and sparking between hardware could cause television or radar interference over 100 megacycles within a circular area of several miles in radius. However, such high frequency noises attenuate rapidly as they travel along the transmission line. Thus, their effect is largely localized as a point source of radiation. In general, they can

* See Attachment No. 3

be detected and pin-pointed rather easily by means of directional antennas with, or without the method of triangulation.

The ultra-high frequency noises are very objectionable to commercial and military communications and guidance systems. Especially with the advent of extra-sensitive radio telescopes, such noises are intolerable even with a magnitude of a few microvolts. Some unattended recording devices were developed to monitor UHF and VHF noises.(5) It appears that UHF noise influence is an area that the radio noise conscious groups of the power industry may have to pay more attention to in the future.

6. MYSTICS OF TRANSMISSION LINE NOISE

Conductor sizes or diameters for transmission lines below 230 KV are often determined by their current carrying capacities rather than the criterion of radio noise. In most cases, the calculated surface gradients of these conductors are much lower than that required to produce corona or radio noise. Laboratory tests on such samples at their operating voltages also confirm that they are either free of corona or with intermittent corona of extremely low magnitude. However, when the same conductors were used on the line, RI Levels of concernable magnitudes were measured in fair weather; thus the mystics of transmission line noise.

One of the theories was postulated by Newell and Warburton[6]. They believe that conductor noise can be produced by the foreign materials such as vegetation and insects that come in contact with and then adhere on the conductor surface.

Tests (7,8,9) made in the laboratories have indicated that not only the type of insulating materials but also their sizes have a profound influence in the magnitude of corona or level of radio noise as well as the inception of such phenomena. Tests also showed that corona discharges emanating from insulating points are during the positive half cycle of the 60 cycle voltage. Field measurements[10] have shown that it is this so-called "positive corona" that is responsible for most of the RI on high voltage lines.

Mr. Warburton has made numerous observations* in the field, primarily at night, on 230 KV lines in New England

* See Attachment No. 4

and framentary confirming data have also been obtained from 345, 500 and 700 KV circuits. Portions of insects and other dielectric particles of about 1/32" in length were actually removed from the conductors by means of a special "Duxseal" covered roller with a hot stick where, and while, the visible plume discharges were emanating. Accumulated data have given convincing evidence that the critical length and conductance of the few foreign particles in each span are responsible for producing significant level of noise to affect the RI level of transmission lines in fair weather. Since this thesis of explaining the mystics is supported by both laboratory and field tests, it appears that the next challenging step is to find a means to suppress such plume discharges through an intensive theoretical and experimental study of the phenomenon.

BIBLIOGRAPHY AND ATTACHMENTS

1. "Method of Measuring Radio Noise", Report of the Joint Coordination Committee on Radio Receiption of EEI, NEMA and RMA -- See NEMA Publication 107, New York 1940

2. "The Calculation of Attenuation Constants for Radio Noise Analysis of Overhead Lines," G.E. Adams, L.O. Barthold, AIEE Transactions, Vol. 78, Pt. III, Pp. 975-81 (Dec. 1960)

3. "Radio Noise Propagation and Attenuation Tests on Bonneville Power Administration McNary-Ross 345-KV Line," G. E. Adams, T.W. Liao, M.G. Poland, F.J. Trebby, AIEE Transactions, Vol. 78, Pt. III, Pp. 380-88 (June, 1959)

4. "Radio Noise from High Voltage Transmission Lines," AIEE Radio Noise Subcommittee Report, Table I

5. "Unattended Recording of VHF Receiver Site Noise," R. E. Bloor, AIEE Conference Paper No. 57-1045 (Oct, 1957 - Fall General Meeting)

6. "Variations in Radio and Television Interference from Transmission Lines", H. H. Newell, F. W. Warburton, AIEE Transactions, Vol. 75, Pt. III, Pp. 420-29 (June, 1956)

7. "Effect of Atmospheric Contamination on Generated Radio Influence Voltage", by C. J. Miller, Jr., AIEE Conference Paper No. 56-1046

8. "Relationship between Corona and Radio Influence on Transmission Lines, Laboratory Studies, I-Point and Conductor Corona," T. W. Liao, W.A. Keen, Jr., D. R. Powell, AIEE Transactions, Vol. 76, Pt. III, Pp. 530-40 (Aug. 1957)

9. "Radio Influence Voltages Caused by Surface Imperfections on Single and Bundle Conductors," T. W. Liao, AIEE Transactions, Vol. 78, Pt. III, Pp. 1038-46 (Dec. 1959)

10. "Corona Tests on Hardware for EHV Transmission Lines," O. Nigol and J. Reichman, Ontario Hydro Research News, Vol. 14, No. 3, Pp. 1-7 (1962)

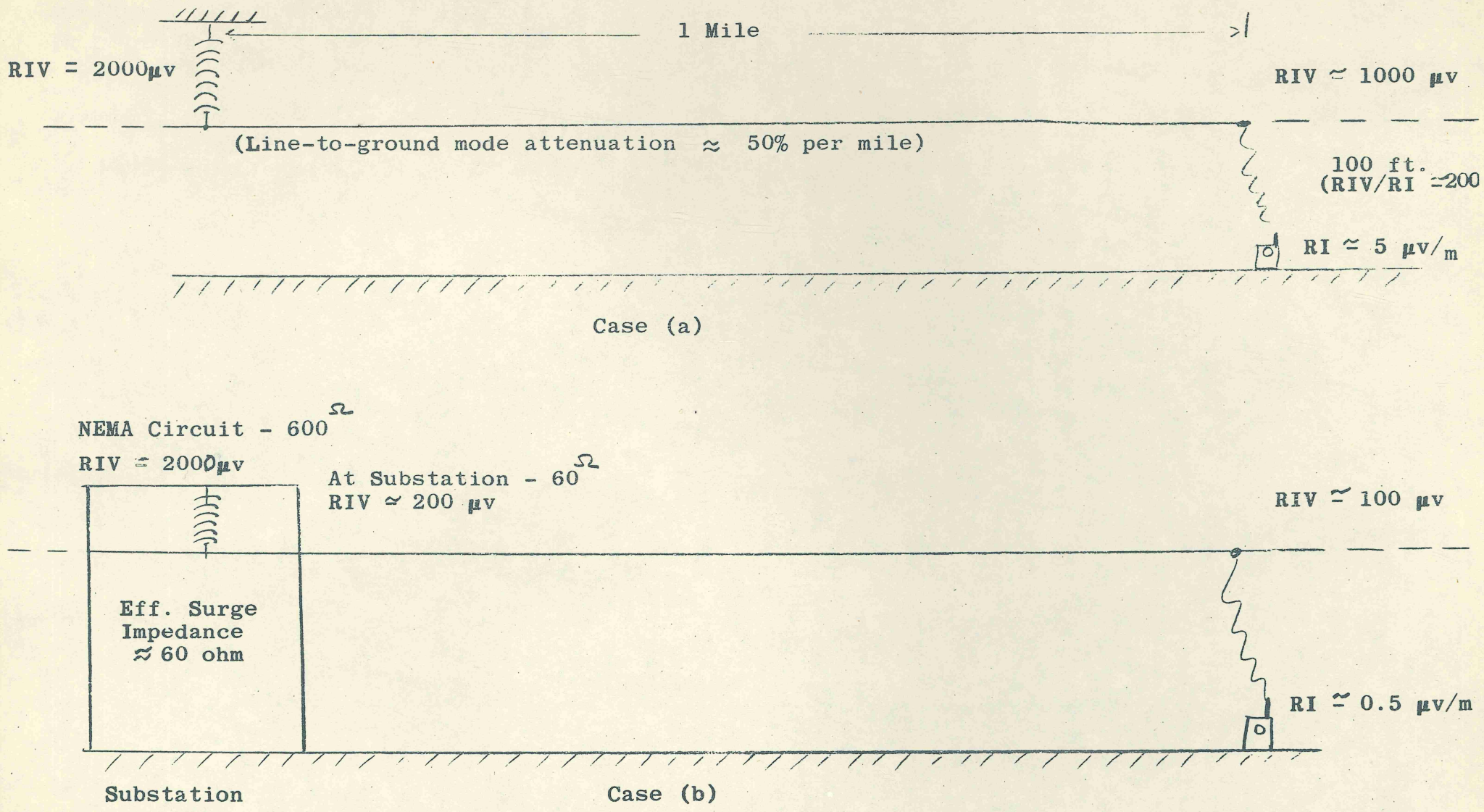

FIGURE 1 - SCHEMATIC DIAGRAM ILLUSTRATING ATTENUATION OF RADIO NOISE FROM A NOISY INSULATOR STRING
(a) INSULATOR STRING ON A TRANSMISSION LINE
(b) INSULATOR STRING IN A SUBSTATION

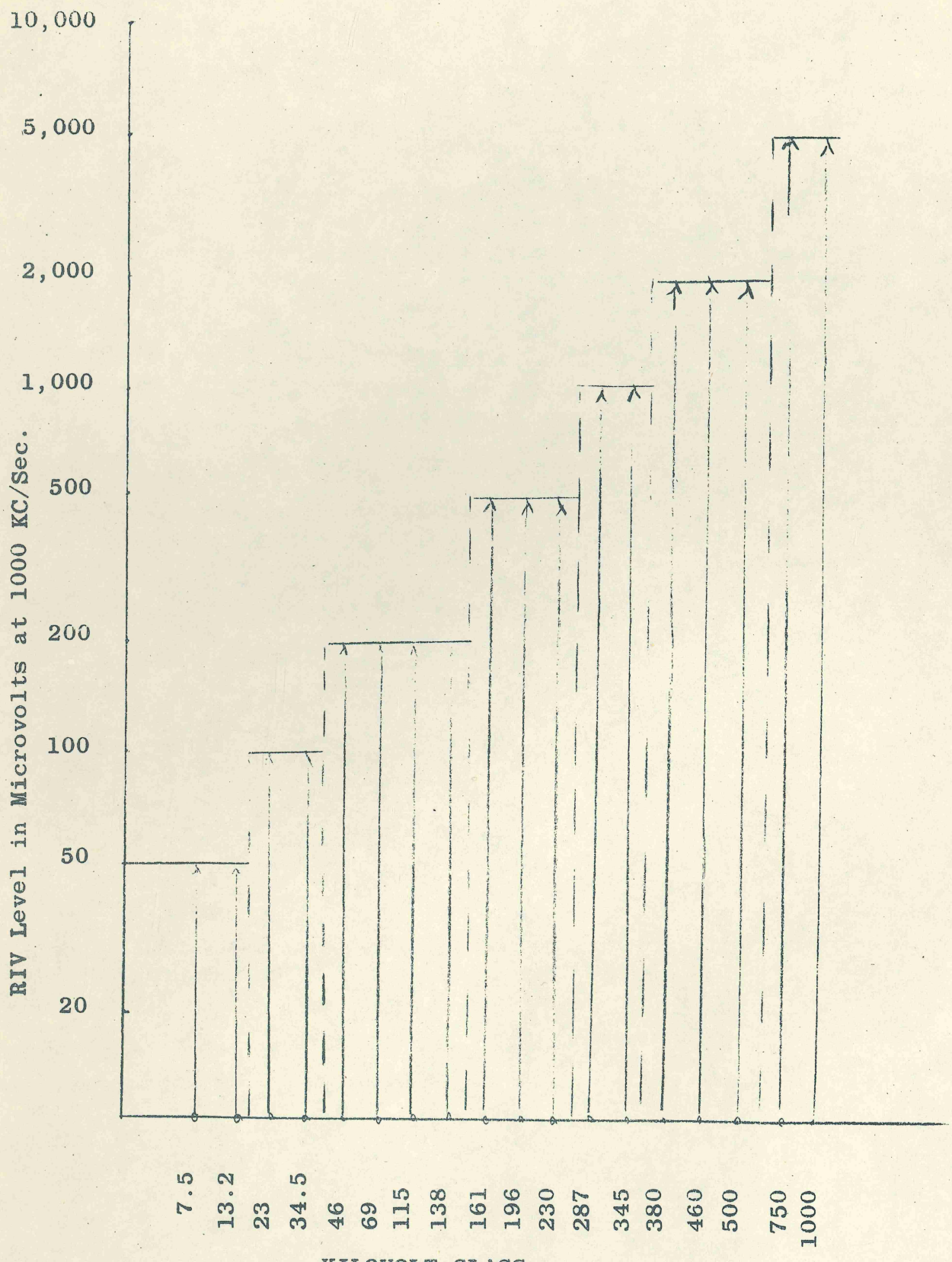

FIGURE 2 - NEMA CIRCUIT RIV LEVELS FOR INSULATORS AND HARDWARE ASSEMBLIES FOR VARIOUS VOLTAGE CLASSES AT A TEST VOLTAGE 110% OF NOMINAL LINE-TO-GROUND VOLTAGE

MEMBERSHIP - WORKING GROUP

on "LINE AND STATION COMPONENTS"

OF RADIO NOISE SUBCOMMITTEE

P. L. Bellaschi
Consulting Engineer
7417 S. E. Yamhill Street
Portland 16, Oregon

H. H. Brustle
General Electric Company
Bldg. 9
Pittsfield, Massachusetts

F. Reed Dallye
Aluminum Company of America
536 Alcoa Bldg.
Pittsburg 19, Pennsylvania

F. A. Denbrock
Commonwealth Associates
209 East Washington Avenue
Jackson, Michigan

C. D. Fiero
Mechanical Engineer
Lapp Insulator Company
LeRoy, New York

J. Kaminski, Jr.
Insulator Division
General Electric Company
P. O. Box 57
Baltimore 3, Maryland

J. R. Leslie
Research Division
Hydro-Electro Power
Commission of Ontario
620 University Avenue
Toronto 2, Ontario, Canada

T. W. Liao (Chairman)
Engineering Research
General Electric Company
6901 Elmwood Avenue
Philadelphia, Penna. 19142
SA.4-1500, Ext. 3221

C. J. Miller
Research Engineer
Ohio Brass Company
Barberton, Ohio

A. C.Neaderland
Project Engineering Section
Burndy Corporation
Norwalk, Connecticut

H. H. Newell
Worcester Polytechnic Institute
Worcester
Massachusetts

W. E. Pakala
Westinghouse Research laboratory
Beulah Road, Churchill Borough
Pittsburg 35, Pennsylvania

B. M. Pickens
Engineering Department
Anaconda Wire and Cable Company
Hastings-on-Hudson, New York

L. N. Stone, Dept. Head
Electrical Engineering
Oregon State College
Corvallis, Oregon

P. D. Tuttle
Aluminum Company of America
Massena
New York

F. W. Warburton
New England Power Service Company
939 Southbridge Street
Worcester 10, Massachusetts